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Scaling Up or Scale-making? Examining Sociocultural Factors in a New Model for Engineering Mathematics Education

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As part of his Pacesetters efforts, Prof. Anderson led the charge to create a new BA in CS degree at CU that allows students in Arts and Sciences to earn a degree in computer science. This new degree program was first offered in Fall 2013 and had 240 students enroll during its first semester and now has more than 900 majors four years later.

He also organizes and hosts the annual NCWIT Colorado Aspirations in Computing Award for the past seven years. This award recognizes the computing achievements of female high school students in Colorado and encourages them to enroll in computer science at the college level. Over 400 young women in computing have been recognized by this event since 2010.

Prof. Anderson received his Ph.D. in Computer Science in 1997 at the University of California, Irvine. His research interests include hypermedia, the design of reliable large-scale software infrastructure, the design and implementation of data-intensive systems, and the design of web application frameworks.

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Keywords: engineering mathematics, curricular reform, Wright State Model, scale-making, educational anthropology, spatiotemporal scales

Abstract

Researchers have pointed to Wright State's *Introductory Mathematics for Engineering Applications* course as a model for undergraduate engineering education curricular reform. The work behind the Wright State Model (WSM) demonstrates that adoption of its introductory course can increase engineering student retention, motivation, and academic success (N. Klingbeil, Mercer, Rattan, Raymer, & Reynolds, 2006; N. Klingbeil & Bourne, 2013), and can remove "the first-year bottleneck" associated with the traditional first-year calculus sequence (Ohland, Yuhasz, & Sill, 2004; N. Klingbeil & Bourne, 2013; Long, Abrams, Barclay, & Paulson, 2016). Klingbeil & Bourne (2013) point to the promise of the Wright State Model in engineering education reform, claiming that the model "is designed to be readily adopted by any institution employing a traditional engineering curriculum… *should it be sufficiently scaled…* the Wright State approach has the potential to double the number of our nation's engineering graduates, while both maintaining their quality and increasing their diversity" (p. 10, emphasis added). In our analysis, we reconsider the "diffusion" notion of "scaling" as it is typically used in educational research (McDonald, Keesler, Kauffman, & Schneider, 2006), proposing instead that innovations and adaptations are better conceived in terms of what educational anthropologists have called "scale-making" (Nespor, 2004). According to this perspective, scale-making is an active process of forming connections between, on one hand, new practices such as the WSM course, and on the other hand, existing networks that operate at a broader spatiotemporal scale—such as classrooms, course scheduling, course numbering, curricular flowcharts, and instructional staffing and student registration practices.

This paper draws on a qualitative dataset of student responses to biweekly "reflection questions" integrated into routine course activity in a pilot implementation of a Wright State-like *Engineering Mathematics* course. Alongside auto-ethnographic data from the course instructor and coordinator, this dataset illustrates the transformations involved in the scale-making process, and enables tracing the consequences of these transformations for the *identities* of people and social collectives involved in the course.

Introduction

This paper reports on the results of a study of an implementation of the Wright State Model for *Engineering Mathematics* at one university. Consistent with the LEES call for proposals, we adopt a human science theoretical approach to the study of teaching and learning as socially, culturally, and historically situated phenomena (Penuel & O'Connor, 2010). We focus in particular on implications of a curricular innovation directed towards an institution's goal to broaden engineering participation and promote success for all students, regardless of incoming mathematics preparation levels, within a selective undergraduate engineering program.

The Wright State Model is a semester-long math course that teaches fundamental concepts of *Calculus 1, 2,* and *3*, and *Differential Equations* in an engineering context through hands-on laboratory experiences and application-rich problems. The WSM is designed to disrupt the traditional rigid sequencing of undergraduate engineering curricula by de-coupling mathematics prerequisites from engineering coursework. In this model, undergraduates are introduced to mathematical tools in a one-semester course that are sufficient to enable them to get started and make progress in technical engineering coursework, regardless of their progression through the traditional mandatory mathematics sequence. The WSM does not replace any mathematics courses along the undergraduate engineering degree pathway; rather, it provides engineering students with a strong foundation and justification for learning mathematics, rooted in the utility of math as a tool for engineers (N. Klingbeil et al., 2006).

The course designers suggest that the WSM "is designed to be readily adopted by any institution employing a traditional engineering curriculum…" (N. Klingbeil and Bourne 2013, 10). With a track record of successful replication across a broad spectrum of American engineering and technology schools—including large public engineering colleges, private high school preparatory programs, and community colleges (Klingbeil et al., 2008; Klingbeil, Newberry, Donaldson, & Ozdogan, 2010; Long et al., 2016)—clear evidence exists to support the claim that the WSM can be readily and successfully integrated into an institution's curricula with great potential impact on persistence and retention of engineering students. Whereas prior analyses from Wright State and others have focused primarily on quantitative performance data to map students' incoming ACT math scores to eventual performance and retention in engineering (N. Klingbeil and Bourne 2015), we take an alternate approach to investigate how the WSM fits into the overall ecosystem of engineering education and the undergraduate experience at the Large Public University (LPU) that serves as the site for this pilot implementation.

Klingbeil & Bourne (2013) point to the promise of the Wright State Model in engineering education reform, claiming that the model, "*should it be sufficiently scaled*…, has the potential to double the number of our nation's engineering graduates, while both maintaining their quality and increasing their diversity" (p. 10, emphasis added). In our analysis, we reconsider the "diffusion" notion of "scaling" as it is typically used in educational research (McDonald et al., 2006), proposing instead that innovations and adaptations are better conceived in terms of what educational anthropologists have called "scale-making" (Nespor, 2004). According to this perspective, scale-making is an active process of forming connections between, on one hand, new practices such as the *Introductory Mathematics* pilot course, and on the other hand, existing networks that operate at a broader spatiotemporal scale such as classrooms, course scheduling and numbering, curricular flowcharts, and instructional staffing and student registration practices.

Background: Educational Scales and the Production of Success and Failure

To assess whether a pilot implementation of the Wright State Model positively impacts students at the LPU, we must first consider how we have previously construed success and failure within an undergraduate engineering program. Learning from educational anthropologists and science and technology sociologists, we are encouraged to look deeper at the spatiotemporal scales typically used to measure progress through the engineering curriculum and mathematics learning, reconsidering who created these scales, the reasoning behind their creation, and what it means about our educational systems. As McDermott and Varenne (2006) suggest, the criteria for success and failure within a given context are more telling about the values and history of the educational designers and administrators in charge than they are about the abilities or knowledge of students they are meant to assess. Investigating the spatial and temporal dimensions of the educational scales used to assess students and programs also provides insight into how some scales become permanent or long-lasting while others fall away.

This perspective enables an examination of the functional consequences of schooling on the social and cultural organization of student lives within our local context. Rather than viewing learning as a change in one's internal cognitive state, we undertake a sociocultural examination of how participation in certain programs or activities (like the WSM math class) differentially places students *into connection with* new groups of people, places, or things; and/or *onto certain trajectories* through education that can become meaningful and consequential for their futures. Inspired by actor-network theory (Latour, 1987; Nespor, 1994; Johri, Olds, & O'Connor, 2014; Tsai, 2015), we investigate how students move through space and time, noting the artifacts they interact with, the people they connect with, and the networks they form or break as a result.

While prior work has examined how engineering students are *produced* in the standard undergraduate education curriculum (Packer & Greco-Brooks, 1999; Tsai, Myers, Sullivan, & Louie, 2017), here we turn our attention to how students shape and are shaped by their interactions with diverse sociocultural elements in their learning environments. We examine the educational scales that are utilized in the context of a new WSM pilot *Engineering Math* class, adopting an actor-network viewpoint to analyze how the WSM is doing more than neutrally delivering math content in a particular way; rather, it is providing new territory in which alternative educational scales are created and experienced. These new educational scales disrupt the default patterns of our educational systems, providing alternatives for student movements aside from the "deeply worn channels" and "worn landscapes" that have typified undergraduate engineering mathematics education for decades (Nespor, 1994, p. 15). We suggest that the promise of this curricular intervention thus reaches beyond mathematics education to include the potential for large-scale disruption of traditional patterns in engineering education. We ponder whether such disruptions have the potential to play a significant role in broadening participation in engineering by opening broader access pathways for students not previously deemed "prepared enough" for the pursuit of engineering education.

As engineering and math educators have long studied the factors differentially impacting the success of first-generation and underrepresented minority populations in college calculus courses (Treisman, 1992; Terenzini, Springer, Yaeger, Pascarella, & Nora, 1996; Pascarella, Pierson, Wolniak, & Terenzini, 2004; Ennis, Sullivan, Louie, & Knight, 2013; O'Connor et al., 2015), this work builds on that scholarship and offers a different perspective to analyze how students move through time and space towards undergraduate engineering degrees. Rather than categorizing students as deficient or lacking in mathematical preparation (Louie, Ennis, Tsai, Myers, & Sullivan, 2017), we explore how the WSM pilot / course offers an alternate set of educational scales for students to measure their progress and chart their learning.

Conceptual Framework: Educational Scale-Making

Before proceeding with explanation of our methods of data collection, analysis, and findings, we define the concept of educational scale as it will be used in our analysis. This conceptual or theoretical framework builds on the work of Nespor (2004), who defines educational scales as “the spatial and temporal orders generated as pupils and teachers move and are moved through educational systems; scales are ‘envelopes of spacetime’ into which certain school-based identities (and not others) can be folded” (p. 309). Educational scales are consequential for students as they define what constitutes success and failure, or belonging vs. not fitting in; as Nespor additionally notes, “scale is thus both an object and a means of power in educational practice” (p. 309).

Nespor (2004) defines five aspects of educational scale:

1. “Scale is made through the **production and circulation of artifacts**: school buildings, desks, curriculum standards, textbooks, tests, plans, homework assignments, and so forth… scales can also be defined by interrupting circuits of artifacts. Pupil activities may be tightly bound to artifacts available only at the school…” (p. 310, emphasis added).
2. “Scale is produced by the ways schools move kids (and teachers) physically back and forth between home and school… schooling generates **rhythms and spatialities** that... structure days, weeks, and seasons for teachers, parents, and their kids, and in the process position those parents, teachers, and kids in relation to one another and actors outside the schools” (p. 311, emphasis added).
3. “Educational scale is defined by the spatial and temporal properties of the networks in which people participate... we can characterize these scalings in terms of the ways **schooling brings pupils into association with others** who define different spaces” (p. 311, emphasis added).
4. “Scale has to do with where schooling events are visible and where they are hidden from view... educational scale is in part defined by the way that **aspects of practice are made visible at some sites and invisible at others**” (p. 312, emphasis added).
5. “Educational scale is defined by the way **participants ‘calibrate’ school-based events to events elsewhere**… to make something meaningful is to situate it in spacetime, or better, to put it into motion along certain paths that trace out particular networks of association” (p. 312, emphasis added).

For our analysis, we start by providing examples of how these five aspects of educational scale are evident in standard mathematics courses along the typical undergraduate engineering pathway, as detailed in prior publications (O’Connor, Peck, & Cafarella, 2014; Tsai, 2015; Tsai et al., 2017). At the Large Public University (LPU) under study, students who are identified on the basis of an incoming placement exam as not ready for *Calculus 1* are enrolled into a specially designed *Pre-Calculus for Engineers* course. The overall letter grade students receive in this course becomes a consequential **artifact** for their navigation through the curriculum, as they must receive a C- or higher in order to move onto the subsequent course in the mathematics sequence. Grades are one example of an artifact that is pervasively produced and circulated widely in engineering education. From a scale-making perspective, letter grades are not a natural or neutral means of assessing ability; they *produce* ability, of certain kinds, measured in certain ways, as a widespread “object and means of power” in engineering education.

The *Pre-Calculus for Engineers* course and subsequent courses along the standard mathematics sequence have well-known **rhythms** and **spaces**: 50-minute lectures are held three times a week in large lecture halls holding 100+ students, 50-minute recitations are taught in smaller rooms of 30+ students each, each course has three midterms and one final exam per semester. These

rhythms and spatialities bring distinct groups of students into **association** with one another, instructors, and TAs, as some students find a specific instructor or TA from whom they learn best, others develop study groups or find office hours to attend, while still others choose to work in isolation or with internet resources rather than collaborate in person with other students. The work processes students use to complete homework assignments and other course tasks are often hidden or **invisible** to the instructional staff, as rumors and suspicions of cheating or misuse of online solution guides and homework helpers run rampant among these mandatory large-enrollment undergraduate courses.

Finally, the progress of students through the curricular chain of *Pre-Calculus* to *Calculus 1*, to *Calculus 2*, to *Calculus 3*, to *Differential Equations & Linear Algebra*, is frequently used as an informal means for students to **calibrate** and compare their own progression through their degree programs to the progress of their peers. As implied by curricular flowcharts (another important **artifact)**, the default progression for engineering students begins in the first semester with *Calc 1*, proceeding onwards through the math sequence and ideally completing the required courses by the fourth semester of their undergraduate careers. Consequently, students classified as not ready for *Calc 1* who start at *Pre-Calc* in their first semesters are already "behind" their peers from the start of their college experiences while students who place into *Calc 2* or *3* their first semesters are "ahead." Feeling behind rather than ahead can be potentially detrimental to student attitudes and feelings of belonging in engineering, not to mention development of engineering identity and desires to persist along engineering degree pathways (Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008; Meyer & Marx, 2014).

The brief examples provided above illustrate educational scale as observed within the standard required mathematics sequence at the LPU. This paper utilizes the definition of educational scale as operationalized via the five aspects to identify the alternative educational scalings that arise in the pilot implementation of the WSM within the LPU context. Furthermore, this paper compares these alternate scales to their more traditional and prevalent predecessors. By mapping where these scales diverge and converge, we are able to understand more about the systems of power in place that construct, maintain, and reify these scales, raising questions for "how some scales become more lasting or influential than others" and additionally which scales *should* be used to assess engineering students (Nespor, 2004, p. 313).

Background: Research Context and Participants

The pilot WSM implementation at the LPU occurred during a fall semester with 23 first-year, first-time engineering students all new to the institution. The specific instantiation of the WSM at the LPU is referred to as *Engineering Mathematics* as its official course title and abbreviated as *Engineering Math* throughout this research paper. While the classroom was designed for 32 students and 32 was the desired pilot class size, only 23 students felt compelled to stay enrolled in the course for the majority of the semester. Students were selected for the 4-credit course based on their math placement; all were classified as ready for *Pre-Calculus* rather than *Calculus 1*. All students enrolled in *Engineering Math* were simultaneously enrolled in *Pre-Calculus*, meaning that they took a minimum of 8-credit hours of mathematics during their first semester of engineering school. Students who dropped the course cited a lack of advance information about the class, that the course was not required or mandatory for their degree programs, and that they didn't want to take that many math credits in the first semester (see Tsai et al., 2018 for more details on student enrollment and start-up implementation issues with the course).

The demographics of the 23 pioneering students are included in Table 1. *Note that one of the 23 formally withdrew from the course after the tenth week; 18 of the remaining 22 (82%) agreed to participate in this research study. The qualitative data presented in this paper is based on these 18 consenting students.

Table 1. Demographics of *Engineering Math* students compared to *Pre-Calc* and first-year cohorts.

	Engineering Math	***Pre-Calc***	**First-Year LPU Cohort**
Engineering students enrolled	**N=23***	**N=69**	**N=851**
In-state residents	87%	64%	66%
International	4%	9%	5%
Male	65%	58%	63%
Underrepresented minority	78%	39%	21%
Low income	74%	39%	19%
First-generation college	61%	41%	17%
"Access" program participant	61%	29%	5%
ACT math min	20	20	19
ACT math max	28	32	36
ACT math average	25	26	30
High school GPA min	3.02	2.70	2.97
High school GPA max	4.00	4.00	4.00
High school GPA average	3.77	3.82	3.93

The *Engineering Math* pilot implementation included a 50-minute lecture section meeting three times a week, one 50-minute recitation section a week, and one 110-minute lab section each week, consistent with a 4-credit hour class during a 16-week semester. All course activities took place in a unique active-learning classroom dedicated to *Engineering Math*. Students worked in pairs to complete weekly laboratory exercises, with the first pairings determined by student choice, and the second and third pairings prescribed by the instructor. Each pairing lasted roughly five weeks, ensuring that students worked with at least three different peers during the semester.

The course was supported by one instructor and two dedicated teaching assistants (TAs), with all three members of the instructional staff holding at least two office hours each week. One TA, Herman, also worked as a student staff member in one of the student-focused hands-on learning engineering laboratories on campus, while the other TA, Mary, also worked as a tutor for the engineering college and held additional office hours in one of the on-campus engineering student dormitories. Both TAs were engineering majors simultaneously pursuing K-12 secondary teaching licensure in mathematics, so were specially trained in math pedagogy and optimally qualified to assist students in the WSM pilot implementation (Zarske, Vadeen, Tsai, Sullivan, & Carlson, 2017). Further details about the start-up and implementation of the WSM at the LPU in the form of *Engineering Math* are available in Tsai et al., 2018.

Methods

The dataset utilized in this paper includes student responses to qualitative reflection questions collected on a biweekly basis during the semester to learn firsthand from students' own words their feelings regarding course activities and content during the 16-week semester. Students were required to submit formal responses to these questions, constituting 10% of their overall semester grade. The reflection question responses were graded based on adherence to basic requirements and the depth of thought and consideration demonstrated in the response text. The full set of reflection question prompts is provided in Appendix A and a sample reflection question grading rubric is included in Appendix B.

When first received by the research team, the qualitative reflection question responses included student identifiers, however these identifiers were removed and replaced by pseudonyms for analysis and presentation. For this paper, the textual data were combined on a respondent-by-respondent basis to enable an at-a-glance view of a participating student's experience over the course of the semester. As additional qualitative data collection is planned in the form of in-depth interviews with students who took *Engineering Math* and students who dropped *Engineering Math*, no formal coding scheme has yet been implemented on the reflection question response subset of qualitative data.

In addition to the qualitative reflection question responses, auto-ethnographic narrative data from the course instructor and coordinator as well as comments from the two TAs are included in this paper where applicable to illustrate the alternative educational scales created in the *Engineering Math* class. The TAs had access to the students in the residence halls and after hours, providing perspectives to supplement the data gathered through the formal research and assessment activities. The data presented in this paper, while preliminary, represents a first-pass attempt at mapping and describing the aspects of alternative educational scales to illustrate the active process of scale-making occurring throughout the implementation of the *Engineering Math* pilot course. This paper specifically addresses the following **research questions**:

1. What educational scales are being created in *Engineering Math?*

2. How do the educational scales of *Engineering Math* become lasting, influential, or insignificant among the scales of the larger institution in which the course is embedded?

Analysis Limitations

Prior to presentation of our findings, we wish to qualify that these are preliminary analyses with a limited dataset, intended to illustrate the potential of *Engineering Math* to create alternative educational scales that exist alongside the traditional educational scales used to measure and track student success and failure in required mathematics courses. At this stage, we are not asserting that the educational scales generated by *Engineering Math* will become lasting or that they are better or more prevalent than the educational scales that already exist at the LPU. Instead, we hope that this analysis provides a new perspective to consider the subtler ways in which an educational innovation such as the *Engineering Math* course may be impactful to students and their future trajectories aside from the obvious consequences to their course schedules and progression through the required courses.

As this work is relatively new and analysis is ongoing, we note that there is no shortage of evidence pointing to the dominance of the traditional educational scales over those created by the fledging pilot implementation of a single *Engineering Math* class in one semester. Rather than concern the analysis with comparing which scale is better, bigger, or more prevalent, we seek to demonstrate the possibility that alternate educational scales can be created and expressed in the context of an educational innovation like *Engineering Math*. Further data collection and analysis is required to determine the scope of these alternative educational scales, though this paper marks the start.

This paper is also an exploration to determine if this conceptual approach of describing scale-making as an outcome of the *Engineering Math* course is meaningful and useful to an audience of engineering education researchers. We are curious to see if this process of mapping out alternate scales will find resonance in a broader communication community, one outside our local context (Walther, Sochacka, & Kellam, 2013). Rather than seeking to generalize from these findings or make definitive policy changes based on how alternate educational scales are made or lived, we wish to highlight their existence and comment on their divergence or convergence as compared to existing educational scales whose spatial and temporal features have gone largely unexamined in engineering education in the context of curricular reform.

Findings

Drawing on the five aspects of educational scale as defined by Nespor (2004) and presented in the Conceptual Framework section, we present narrative data segments and excerpts from qualitative student reflection responses to illustrate how alternative scales are made during the *Engineering Math* pilot implementation.

1: *Alternative scales made through the production and circulation of artifacts*

A new active-learning classroom was designed and built at the LPU to facilitate the lectures, labs, and recitation activities scheduled throughout the course during an entire semester (see Figure 1). In lieu of a projector, the classroom included four 60-inch LCD screens dispersed around the room to facilitate an active-learning, collaborative style of seating in which students face one another rather than one central "front" of the classroom. Numerous whiteboards were mounted on all four classroom walls, interspersed with the LCD screens. The classroom also included new equipment—including oscilloscopes, power supplies, function generators, multimeters, breadboards, stopwatches, weight sets, rulers, etc.—all stored in equipment carts adjacent to the classroom desks. Finally, the classroom included computers with relevant engineering software (MATLAB and Excel), with each student pair having access to a desktop computer, an equipment cart, a desk, and a whiteboard.

Figure 1. Panoramic view of the *Engineering Math* classroom setup.

Fundamentally, scheduling students for this new class in this new room involved the making of a new spatiotemporal scale. Instead of circulating through the well-worn pathways of the existing classrooms and lecture halls in the Engineering Center, students in *Engineering Math* occupied and circulated around this new classroom, located in an area of the building where first-year students do not typically attend classes. As the laboratory activities required students to utilize the equipment housed in the carts inside the room, students were bound in space and time to complete the labs during the designated weekly time, thus anchoring their weeks around this mandatory event of a "lab"—another illustration of the educational scale created by scheduling students for course events in the new, dedicated classroom.

Continuing to consider the production and circulation of artifacts in *Engineering Math* as one means of educational scale-making, many students found their interactions with the material artifacts in the classroom and equipment carts—including the classroom itself—to be meaningful. One student, Vincent, explains:

> I am excited about this class for the fact that we are the first people ever taking the class at [LPU]. This is exciting to me because we are pioneers and we get to experience everything firsthand. Because we are the first students taking the class we get the new equipment and perks of having everything new. In my old school, all the equipment was mistreated and there was always something that was broken or just missing. Being the first to get the equipment is great because we know everything works and I know that we can take care of it so that other students in the future can use it without having to worry about whether or not it's broken. Being able to be the pioneers and to have great equipment is what excites me the most for the class.
>
> *~ Vincent, Reflection Question 1, Week 1*

For Vincent, access to new equipment and materials like this was clearly an aspect of educational scale he had not experienced at his high school. From early in the semester, he felt ownership over the equipment, declaring he knows "we can take care of it" so that future students can use items "without having to worry" about them being broken or missing. Vincent's expressions of excitement and accountability about being a pioneer in the *Engineering Math* class contrasts to his other first-semester courses. The other established courses operate on a different educational scale, featuring different artifacts in circulation: well-worn desks and chalkboard in traditional lecture halls rather than the computers, screens, and materials used in *Engineering Math*.

Many students commented on enjoying the various new material artifacts present as part of *Engineering Math*, including Gabrielle and Lucas:

> My favorite aspect of the class was the whiteboards. Working on the whiteboards forced you to work the problems out, it gave us the chance to practice in class rather than just take notes. I wish we had done more work on the whiteboards... it was convenient and engaging, two important things when learning, at least for me.
>
> *~ Gabrielle, Reflection Question 7, Week 15*

> I'd have to say my favorite lab was the circuits lab. We got to blow up resistors alongside forming an understanding of how to build a circuit. This lab was my favorite because it was exciting and it made me feel very comfortable in working on circuits upon completion of the lab.
>
> *~ Lucas, Reflection Question 7, Week 15*

These students mention physical aspects of the classroom (whiteboards and resistors) that they interacted with and associate with positive learning outcomes. The ability to "blow up resistors" or "work on the whiteboards" represents an alternate aspect of educational scale not present within the everyday activities of the rest of their coursework, and were cited by students at semester end as being their "favorites"—clearly meaningful and personally memorable.

We close the discussion of this aspect of educational scale, the production and circulation of artifacts, with one more student account:

> The most memorable aspect of the *Engineering Math* class would be the amazing room we had at our disposal. It has been an amazing place to do homework and have fun. The whiteboards and computers make the space perfect for solving problems and getting through homework. It is also nice because there are no windows to the outside, so you don't see the sun come up when you pull an all-nighter.
>
> *~ Oliver, Reflection Question 7, Week 15*

As a new classroom and space on campus for these students to inhabit as part of the course, it clearly left an impact on students like Oliver who calls it "amazing" twice in the above response. He mentions doing homework and having fun in the room in the same sentence, more evidence of an alternative educational scale, as these are not items typically mentioned by first-year engineering students in the same breath, linked by a classroom space. While study spaces in residence halls or libraries may also provide room for students to do academic work and have fun simultaneously, utilizing a dedicated classroom space featuring new physical artifacts within the main engineering academic building for unrestricted student use is a unique feature of *Engineering Math*. Considering the first aspect of educational scale-making as defined by the production and circulation of artifacts, we see how the creation of the *Engineering Math* classroom and scheduled activities within the room represent a new educational scale at the LPU.

***2:** Alternative scales made through the generation of rhythms and spatialities*
We next examine the production of alternative rhythms and spatialities—habits and routines in space and time—created as students participated in the pilot *Engineering Math* implementation. As Oliver alludes to above, the *Engineering Math* classroom was made available to students at all hours, so they could stay in the room all day and all night if desired. Oliver's comment that the room is "nice because there are no windows to the outside" is partially humorous but also reinforces the point that the room offered a distinct spatiality or location for them to exist within. As the only course scheduled in the classroom, students were specifically given 24/7 card-swipe access, a rare privilege for first-year students in their first undergraduate semester. Miguel explains:

> I am also excited that the classroom will only be for students that are taking *Engineering Math* and that they are the only ones that would be able to go into the classroom. I am excited because the classroom would be a good place to go when I want to study or work on homework.
>
> *~ Miguel, Reflection Question 1, Week 1*

The granting of access to the room enabled the enrolled students to structure their daily habits around a new material resource: a "good place" to study or work on homework. As the Engineering Center at the LPU is typically packed with students studying and working on homework or looking for places to study and work collaboratively, convenient and public study space is a desirable and scarce commodity. Having access to a special classroom with tables, desks, and computers readily available 24/7 is another example of the alternative scales or spatialities generated by the *Engineering Math* course.

One student in particular, Adrian, utilized the *Engineering Math* classroom as his personal study hall and was legendary for spending evenings and early mornings in the room. His friends often caught him sleeping in the classroom, going as far as snapping his photo while he was sprawled across the chairs with a timestamp of 3:44 AM and posting the photo on a whiteboard in the classroom captioned "Adrian's Office Hours." This became a running joke throughout the semester, as students who studied until the early hours of the morning in the *Engineering Math* classroom would describe their activity as "attending Adrian's office hours":

> The room we were given access to has brought a lot of memories. One of the more notable ones was "Adrian's office hours." I will never forget the 3:00 AMs with the legend himself who never ceased to amaze me with his ability to pull consecutive all-nighters.
>
> *~ Tomas, Reflection Question 7, Week 15*

> One of the most memorable moments in *Engineering Math* class is seeing Adrian sleeping. It was memorable because that is when I started to see the struggle of college. It was also memorable because that is when Adrian's office hours started. I really enjoyed the room because this was the room where I did my homework. I, in general, enjoyed the time that I spent in this class.
>
> *~ Miguel, Reflection Question 7, Week 15*

"Adrian's office hours" would not have existed without access to the *Engineering Math* classroom, as it was a private space shared by only 22 other students. While students certainly fall asleep in the various Engineering Center spaces at the LPU, rarely does it become a notable or cultural event warranting the "office hour" designation. As Tomas refers to Adrian as "the legend himself," we even begin to see how the unique rhythms and spatialities of the *Engineering Math* classroom enabled the creation of not just a new educational scale but also assisted in identity formation: Adrian as legend, Adrian as a holder of office hours, Adrian as evidence of "the struggle of college." These identities were enabled by, and are evidence of, the alternative educational scale generated by the all-hours access to the *Engineering Math* classroom as part of enrolling in the course.

While "Adrian's office hours" is a standout example of the alternative rhythms and spatialities enabled by *Engineering Math*, it is notable that the experience of pulling an all-nighter remains a common occurrence across engineering undergraduate populations. Though rare for the all-nighter to take place within a classroom environment that students feel comfortable enough to fall asleep in repeatedly, and be documented by friends and classmates, the experience of staying up to cram for exams or complete assignments is a widely accepted facet of being an engineering student. This suggests that while *Engineering Math* may enable alternate educational scales, the outcomes of these scales may serve to reinforce dominant norms and behavioral patterns at play within the larger institution and broadly within the engineering culture.

***3:** Alternative scales made through association with other students or entities defining different spaces*

The *Engineering Math* class also generated alternative scales in the ways it joined together students from various extracurricular programs, enabling the formation of relationships, friendships, bonds, and connections that otherwise would not have occurred. Many students enrolled in *Engineering Math* were also members of LPU's *Access Program* (61%)—a broadening participation program providing an alternate entry into LPU for students from under-resourced and underrepresented groups in engineering (Ennis et al., 2016; Knight et al., 2013). Where students in the *Access Program* previously reported feeling segregated and separate from the mainstream undergraduate engineering population at LPU, the *Engineering Math* class offered a space for *Access Program* students to mix with non-*Access* students within an immersive, hands-on, collaborative engineering environment.

An early concern of curriculum developers, administrators, and instructors was that the *Access* students would clump together, and non-*Access* students would stick together with other non-*Access* students. Fortunately, these concerns were unfounded, as the differences in program membership were not consequential for how students interacted in the course. As evidenced by lab partner pairings and informal working groups observed during the semester, participation in *Access* or non-*Access* had little or no apparent impact on choice of homework partners or collaboration. Furthermore, since all *Access Program* students resided in the same on-campus dormitory, and it was the same dormitory in which TA Mary held additional residential tutoring hours, *Access Program* students frequently invited non-*Access* class members to the dorm for additional tutoring help from Mary on nights before deadlines for homework assignments and laboratory reports.

While all classes and experiences bring together diverse people who would otherwise not have a structural reason to interact, meet, or make connections, we see the *Engineering Math* class as bringing students together into meaningful association with immediate consequences for their feelings of belonging within engineering and for making lasting friendships as a result of the course. In Gabrielle's words, "What made this class even better was the fact that it was small, mostly everyone became comfortable with each other" (*Reflection Question 7, Week 15*). This comfort and familiarity with one another in the classroom is a far cry from the climate generated by large-scale lectures attended by more than 100 students—another example of the alternate educational scales created in the *Engineering Math* pilot implementation.

***4:** Alternative scales made visible at some sites and invisible at others*
Getting the *Engineering Math* pilot course off the ground required significant institutional commitment to prepare the classroom, procure lab equipment, hire the instructor and TAs, and most significantly secure departmental agreements to ensure that *Engineering Math* would count towards their degree programs, and more. The *Engineering Math* pilot was a cross-college initiative requiring cooperation across senior leadership, specific departments, advisors, facilities and programs, leading to the course being highly visible among the administration, staff, and faculty of the college who had a stake in its success and could hold each other accountable for that success as a result. In contrast, undergraduate engineering students throughout the college were largely unaware of the existence of the course, as it was advertised exclusively to incoming first-year students identified as being good candidates for the course. Thus, participants in this largely invisible course had no "word of mouth" from upper-class mentors, friends or acquaintances about the worthiness or unworthiness of the course.

This level of course invisibility among the student body is another contrast in educational scale as compared to the well-established undergraduate engineering mathematics curriculum that begins at *Calc 1* before proceeding to *Calc 2* and *3* and finally *Differential Equations & Linear Algebra*. Prior work has illustrated how the visibility or invisibility of a student's trajectory along standard curricular flows is critically important for feelings of legitimacy and belonging in engineering (O'Connor et al., 2014). For example, the fact that students describe themselves as ahead or behind based on their progression through the mathematics sequence provides evidence of the power of the curricular flowchart as an artifact that organizes and stabilizes the standard educational scales used to measure progress towards obtaining undergraduate engineering degrees. Except to students enrolled in the pilot course, *Engineering Math* does not exist in the traditional sense at the LPU; it does not appear on any curricular flowcharts and is essentially invisible, literally "off the curricular maps" that students use to navigate through the curriculum.

Sample data from two students who dropped *Engineering Math* prior to the first day of classes indicates that the *invisibility* of the course was a deciding factor:

> I didn't understand where the class came from, since I hadn't seen it during the pre-registration period, and I hadn't chosen it during the registration period. I thought it was a mistake in the system. The course description also didn't give me a good idea of the course material, and I didn't want to take a class that didn't provide a good description. It felt vague to me.
>
> ~ *Student #1*

> The factors that affected my choice in taking *Engineering Math* were the amount of

> classes I already have, as well as not knowing much about the class. I was not told much about the class so I didn't have much interest.
>
> ~ *Student #2*

In contrast to the first three aspects of educational scale-making discussed so far in the Findings section, the alternative scales generated by *Engineering Math* in this context of visibility and invisibility were a challenge to the enrolled students rather than an advantage. However, as we find in the final aspect of alternative scale-making, by not appearing on the official curricular flowchart, the class was not constrained by it either. This allowed the class to exist "off the grid," not categorizable by the traditional classifications or identities of students being ahead or behind, enabling the course to disrupt traditional notions of progress along engineering trajectories.

***5:** Alternative scales made through "calibration" of school-based events to events elsewhere*

Finally, we examine the ways *Engineering Math* calibrated with existing networks (and scales) in space and time at LPU and beyond. As discussed above, *Engineering Math* was not officially represented on departmental curricular flowcharts as it was an experimental pilot rather than an established course along undergraduate degree pathways. College leadership required that the pilot course satisfy a degree requirement for all of LPU's engineering majors so that all enrolled students would clearly make degree progress by taking the class, regardless of major choice. As an introductory course, *Engineering Math* would typically be numbered as a 1000-level course to signify its appropriateness for first-year students. However, to also make sure it satisfied a degree requirement across all majors, the only option was to number it as a 3000-level "special topics" course and secure individual departmental agreements so that this unique experimental class could be counted for *technical elective* credit in each degree-granting program—credits usually reserved for upper-division classes. Each department was compelled to agree to this unusual arrangement by direct request of the engineering dean at the LPU, whose strategic support for the class was contingent on replicating the improved retention numbers the *Engineering Math* class/WSM has demonstrated at other institutions (N. Klingbeil et al., 2010; Long et al., 2016). Individual departments were also assured that the 3000-level "special topics" designation would only be used temporarily for the duration of the three-year pilot implementation of the course, after which a more formal adoption of the course would require a new course number and adjustments to departmental curricular flowcharts and other institutional artifacts.

This means of calibrating with the LPU's existing degree programs and course numbering meant that additional messaging was required to convince the incoming first-year students that they were well-suited to take a 3000-level course and to convince the departments that they would not be shortchanging these students by allowing the pilot course to count for a technical elective. Thus, the course number was consequential for calibrating with departmental curricular requirements and student expectations for the course, as Vincent explains:

> What I most hope to get out of this class is a better understanding of what I can expect in my upper-level classes. Since this is a 3000-level class, I can learn a lot on how to manage my life but also how I can improve the things I do to learn. This class will help me learn how to manage the time that I use for daily activities and school and it will also help me better the way I study and the way I take notes. I look forward to the challenge of the class and I know that the difficulties of the class will only help me improve myself and help me become a better student.

~ Vincent, Reflection Question 1, Week 1

In this way, the 3000-level designation signaled to students that they would be learning not just math content but also the expectations and format of "upper-level classes." To students like Vincent, the course also came to represent an opportunity to hone their learning and study skills and be more prepared for future courses along their engineering degree pathways. The unique accommodations made for *Engineering Math* to successfully calibrate with the existing networks of curricular flowcharts and degree requirements is another example of the alternative educational scalings created by the course. Put another way, no other 3000-level courses exist in the engineering college targeted specifically at first-year, incoming students; *Engineering Math* exists alone with the specific combination of course number and student level.

This unique combination of course number and student level disrupts the typical patterns of the LPU and calls into question the meaning of 3000-level and what technical content level is appropriate for first-year students. In addition to learning fundamental calculus and differential equations topics, the *Engineering Math*/WSM curriculum also includes an introduction to MATLAB, which is necessary to complete many of the mandatory laboratory exercises and homework problems. Many of the first-year students had trepidations about learning a programming language and environment like MATLAB, as Esteban explains:

> I am very nervous about MATLAB because I am a terrible coder. I always forget the little things and get the code wrong and get frustrated. I am more of a hands-on person and like to see what I am building rather than coding in commands. Setting up code just doesn't process in my head. I am also worried about how the class is a three thousand level class and that means we are taking junior/senior classes.
>
> *~ Esteban, Reflection Question 1, Week 1*

To Esteban, the 3000-level designation caused concern because it meant that he was taking a "junior/senior class" in his first year. Noting that this was his response to reflection question 1 in the first week of the semester, it is clear that Esteban's initial attitude about programming focused on his own "terrible" coding ability and how his head just didn't "process" setting up code at the start of the course. Yet as the semester progressed, Esteban learned MATLAB. He completed each MATLAB homework problem and laboratory exercise successfully, and reflected on his growing familiarity and understanding along the way:

> My skills in MATLAB are improving and I am willing to continue to learn even more.
>
> *~ Esteban, Reflection Question 3, Week 5*

> After seven weeks of going through the struggles of learning MATLAB, I feel like I have gained a decent grasp on how MATLAB works and writing my own code to solve problems. I know the fundamentals of MATLAB, but still get stuck on complex questions because the content is still new to me and I make simple mistakes.
>
> *~ Esteban, Reflection Question 4, Week 7*

From being a "terrible coder" in week 1 to gaining a "decent grasp" on "writing code to solve problems," Esteban clearly improved his MATLAB skills. He acknowledges knowing "the fundamentals of MATLAB" by week 7—powerful knowledge to have even if he still gets stuck or makes "simple mistakes" while writing code. Furthermore, Esteban expresses a willingness "to continue to learn even more", suggesting a shift in his attitude and approach to learning programming from what he stated in week 1.

After tutoring in Esteban's dormitory one evening, TA Mary related a striking instance of how Esteban's skills and confidence in his MATLAB ability became evident even to students not enrolled in *Engineering Math*. One of Esteban's first-year peers in the Access cohort was lamenting that she was progressing onwards to *Calc 3* the subsequent semester and was nervous that she would thus have to learn how to use MATLAB. Esteban offered to help her learn, explaining how he had learned MATLAB in *Engineering Math*. His peer reacted in surprise, as she was not expecting Esteban at "only" a *Pre-Calc* level to be able to help her out with her future *Calc 3* class. In other words, she was not expecting Esteban to have knowledge that did not match up with the standard curricular flowchart—that despite being classified at a *Pre-Calc* level, he had high-level knowledge that could benefit her even though she was "ahead" of him in math.

Many students use the math curriculum to categorize themselves—and others—as being ahead or behind along the engineering degree pathway (O'Connor et al., 2014). Thus, *Engineering Math* represents a disruption to this oft-used classification scheme. An understanding of MATLAB is a valuable resource in the undergraduate engineering knowledge economy, and teaching MATLAB in *Engineering Math* creates an alternative point of calibration to the standards established by the traditional math course progression. Feeling ahead or behind one's peers in math knowledge and in math courses has been shown to be additionally consequential for engineering identity development, suggesting that the alternative educational scales represented by *Engineering Math* provide an alternate pathway for students to develop engineering identity, aside from the default classification of being ahead or behind in calculus (O'Connor et al., 2015).

Discussion

Our first research question asked, "What educational scales are being created in *Engineering Math*?" Across the five aspects of educational scale, including artifacts, rhythms, associations, visibility and invisibility, and calibration to external events and scales, we have presented data to suggest that alternative scales are being created and lived through the process of administering this new course for the first time at the LPU. From these data, we find a few compelling examples—including "Adrian's Office Hours" and Esteban's MATLAB skills—that suggest ways alternate educational scales generated through the *Engineering Math* course may be impactful for engineering identity development.

One promise of the *Engineering Math* course design and implementation is to provide engineering students with alternate scales by which to measure and track their own progress through the curriculum. In this way, students may find value in their own journey rather than feeling "behind" the default curricular flowchart right from the start if they are not yet prepared to jump into the calculus sequence (O'Connor et al., 2014). Changing the narrative such that "blowing up resistors" or being knowledgeable and experienced in the use of MATLAB also constitute important evidence of a first-year student's *right to belong* in engineering could have significant impact on whether students choose to persist in the field. As noted in the student reflections, doing the hard work required of *Engineering Math* was not a deterrent to student persistence. Rather, the confidence and knowledge gained through applying math to perform engineering in a hands-on way was a perceptible theme by semester end, providing evidence that a course like *Engineering Math* can disrupt traditional educational scales in meaningful ways.

Our second research question asked, "How do the educational scales of *Engineering Math* become lasting, influential, or insignificant among the scales of the larger institution in which the course is embedded?" While our data illustrates the ways alternate educational scales were generated through the *Engineering Math* pilot implementation, we stop short of comparing the scope and impact of these scales to those already in widespread use in the engineering college at the LPU. We need more data across multiple years to be able to address this research question adequately. After a single pilot semester implementation, we continue to collect data to investigate ways the alternative scales may wither away or remain relevant once students have moved through *Engineering Math* and into more mainstream undergraduate engineering curricular pathways.

Subsequent years of course implementation will be far different from the first, as *Engineering Math* will be significantly expanded in year 2 of the three-year pilot. From 23 students, the course will ramp up to ~120 students for the second year, split across multiple lecture, recitation, and lab sections. The lectures will move from the specialized classroom to a different active-learning space on campus to accommodate up to 60 students per section. The labs and recitations will still feature approximately 30 students each, meeting in the specialized *Engineering Math* classroom. This modification is expected to fundamentally change the relationship of enrolled students to course artifacts including the classroom and laboratory equipment, not to mention the impact on the rhythms and spatialities of the course once many more students are given 24/7 card swipe access to the *Engineering Math* classroom and official course activities are split across multiple rooms and meeting times. It remains to be seen how students, staff, and faculty will perceive *Engineering Math* in future years, as the 3000-level course numbering and other aspects of the course may be interpreted in different ways it is expanded to serve more students.

We also expect the scale-up to impact the course's small community feeling, changing the ways students associate with each other across lecture, lab, and recitation sections. Whereas "Adrian's office hours" existed in part because he was one of only 23 students with room access, it remains to be seen if future students will continue to manifest the alternative educational scales as he did. We may find that the experiences and educational scales demonstrated by the first pilot cohort are unique to the rare circumstance of being the only students to have access to a new classroom space, or we may find still other alternative educational scales that are created by the second year implementation of this initiative.

Conclusions

The Wright State Model has been widely adopted and increasingly studied due to its promise as a truly disruptive educational model that has "the potential to double the number of our nation's engineering graduates, while both maintaining their quality and increasing their diversity" (N. Klingbeil & Bourne, 2013, p. 10). The allure of these claims is impossible to ignore for engineering programs across the country. Broadening participation in engineering by opening access pathways for students previously not deemed "prepared enough" for the pursuit of engineering education disrupts most of the institutionalized limitations on both quantity and diversity of the engineering graduate pool. The number of students interested in and "prepared" to study undergraduate engineering are seen as a finite commodity with increased production of engineering graduates an imperative for universities and the nation (Atkinson, 1990; Florida, 2004; Xue & Larson, 2015). The WSM claims to provide remedies to all of these seemingly intractable issues.

The cost of implementing the WSM at the LPU required significant investment on the part of the college and supporting departments in the form of facilities, time, and funding to enable renovations, instructor and TA salaries, computers, and the purchase of requisite laboratory equipment. While not inexpensive, the potential to create an alternative access pathway for populations previously denied engineering access is immeasurable; we hope to demonstrate the bottom-line value of this approach as we track student progress through the undergraduate program across subsequent years.

Combining actor-network theory (Latour, 1987; Nespor, 1994; Tsai, 2015) with the five aspects of educational "scale-making" from the theoretical framework outlined by Nespor (2004), we investigated the pilot implementation of the WSM at a Large Public University. The goal of this conceptual approach of describing scale-making as an outcome of the *Engineering Math* course is to test its value to an audience of engineering researchers and highlight the benefits of alternative educational scales for student identity formation and development. Multiple instances from the qualitative dataset support findings across all five aspects of the educational scale-making conceptual framework. This type of analysis and accompanying findings may help researchers understand how and why the WSM works to increase persistence and retention in engineering majors as observed across many diverse institutions. Beyond the promising indications that preparedness and feelings of belonging may be positively impacted by the pilot *Engineering Math* course, the richness of the experience revealed by the conceptual framework are profoundly encouraging and compel the continuation and expansion of the program as well as continued data collection and analysis throughout subsequent years of program implementation.

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Appendix A. Biweekly Qualitative Reflection Question Prompts

Reflection question instructions: *Using a word-processing program (Google Docs, Microsoft Word, etc.) answer the following questions using full sentences and paragraphs. Your response should be a half-page to a full page, single spaced, 1" margins, size 11 font. Upload your responses to the designated Dropbox before 5:00 PM Friday. Remember that these responses will remain confidential—only the instructor and the TAs will read them.*

Reflection 1 (week 1):
- So far, what are you most excited about in our class?
- So far, what are you most nervous about for our class?
- What do you most hope to get out of this class?
- Any concerns or questions?

Reflection 2 (week 3):
- Consider the two labs (One-Loop Circuit and One and Two-Link Robots) we've done so far. What has been interesting to you in these labs? Have you learned anything about math or engineering that you didn't know before? Have you gained any new skills through doing these labs?

Reflection 3 (week 5):
- We are already one-third of the way through the semester! Next week you will take your first Engineering Math midterm and then we will switch lab partners.
  - How do you plan to study for the midterm? What resources will be useful for you, how long do you plan to study?
  - What have you learned from the experience of working with your lab partner for the last five weeks? What do you plan to do differently or the same in working with your next lab partner?

Reflection 4 (week 7):
- You have now had seven weeks of exposure to MATLAB. Please explain: how comfortable do you feel using MATLAB now compared to when you first started the semester? Imagine if you were working alone, without your lab partner, would you be able to complete an assignment similar to MATLAB Activity 2 from lab this week? What would be easy and what would be challenging for you?

Reflection 5 (week 9):
- Next week in lab, you will be given the choice to complete the lab assignment using MATLAB or Excel. Which one will you choose and why? Which program do you think will be most useful for you as an engineering student at LPU?

Reflection 6 (week 12):
- The Engineering Math midterms are done, with the final exam remaining. What have you learned about studying for exams across all of your classes? How will you study for finals?

Reflection 7 (week 15):
- You've made it to the conclusion of your first semester at LPU. How have you changed, grown, matured, or developed as an engineer and a student during this semester?
- What have been the most memorable aspects of the Engineering Math class? Why?

Appendix B. Sample Reflection Question Response Grading Rubric, Reflection 1, Week 1
Reflection 1 (week 1):

- So far, what are you most excited about in our class?
- So far, what are you most nervous about for our class?
- What do you most hope to get out of this class?
- (optional) Any concerns or questions?

Reflection Grading Rubric

Item	***Fair***	***Good***	***Excellent***
Development of ideas and depth of responses to questions:	Each question is addressed at a basic level	Each question is addressed with appropriate details	Each question is addressed with well-developed details and ideas that show how you've thought about the question
	3	5	7
Adherence to guidelines:	Guidelines not satisfied		Header includes all required information, 300-500 words, 1" margins, size 11 font, single spaced, complete sentences and paragraphs
	0		3
Deductions:	*-1 for each spelling or grammar error*		
Total	**/10**		